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POTABLE WATER TASTE ENHANCEMENT

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to

The National Aeronautics and Space Administration

Johnson Space Center

Houston, Texas

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1.0 INTRODUCTION

Potable water used for manned spaceflight missions is characterized by an unpalatable flat or bitter taste because of contaminants and/or lack of specific ingredients. The absence of taste results from the removal of organic and inorganic compounds normally found in good tasting water supplies. Contaminants in spacecraft water systems which cause disagreeable taste may originate from several sources, including improper cleaning, leaching from incompatible materials, and inefficient removal with subsequest build-up of certain components in recycling systems. The unpalatability of spacecraft potable water dictates the need to (a) establish criteria for the enhancement of taste of purified water; (b) identify contaminants causing disagreeable taste and determine ways of removing them; and (c) evaluate and develop techniques for monitoring and maintaining water quality and palatability. It was intended that the effort under this contract utilize to the fullest extent any applicable information available in the published literature to accomplish (a), (b) and (c) above.

The principal objectives during the first year effort were, therefore, (i) to conduct a comprehensive literature search on the effects of various common water constituents on palatability and the evolution of analytical methods for determining these constituents; (ii) to develop preliminary criteria and specifications for palatable water to serve as guidelines for subsequent phases of investigation; and (iii) to perform laboratory analyses of selected water samples for preliminary evaluation of reclaimed water samples and measurement of chemical constituents related to palatability.

The results of the first year's effort indicated that the total quantity of volatile organics present in spacecraft water must be maintained at some value in the 10-1,000 ppb (parts per billion) range to insure against possible negative palatability effects. Single component concentrations may have to be controlled to lower concentrations depending on the particular component. It was apparent that any further definition of the volatile organics specification would require quantitative data on volatile organics in potable water. The literature search indicated that no published methods were available for these determinations. A considerable portion of the final year effort was, therefore, devoted to the development of a technique for the quantitative analysis of volatile organics in water. The remaining effort was devoted to the further examination of the palatability factors developed during the first year in an attempt to determine which are actually essential for good tasting water.

2.0   LITERATURE FINDINGS

2.1   General Principles of Taste and Odor

There are many factors governing the taste and odor sensations
and a fairly complete discussion requires several hundred pages. There are
several factors which would seem to be more important in relation to water
palatability. Probably the single most important factor is that, while
taste and odor are separate, it is very difficult to dissociate them. This
can be demonstrated by the fact that apparently tasty substances are taste-
less when the nose is held. For this reason one must consider both taste
and odor in discussions of palatability.

Both taste and odor have some fairly specific relations to chemical
constituents which have been described in the literature (1-4). Tastes,
however, are few and well-defined, while odors are ill-defined and subjec-
tive in nature. For the most part (but not conclusively) tastes can be
classified as salty, sour, sweet and bitter. Sapid or tasteful substances
are in a different class altogether than odorous substances. Substances
which have the strongest tastes, such as polyhydric alcohols, sugars,
amides, imides, salts and many mineral acids are odorless. In general,
there appear to be two prerequisites for taste; (1) water solubility and
(2) a molecular configuration which finds its complement in the taste
receptors. Correspondingly, the prerequisites for odor appear to be
(1) volatility and (2) a molecular configuration complementary to one that
occurs in the olfactory receptors. The principle difference then is that
taste requires water solubility while odor requires volatility. It should
also be noted that stimulus of gustation or taste requires parts per million

concentrations in a few cc of water (10^{-6} g quantities); while stimulus of olfaction requires 10^5-10^6 molecules per second for a few seconds (10^{-14} g quantities). Based on the above it would appear that volatile organic compounds amenable to analysis by head space sampling techniques may be important in determining water palatability.

2.2 Sources of Taste and Odor in Drinking Water

Several books have been published which treat the problem of taste and odor in drinking water with varying degrees of completeness. It should be noted, however, that in nearly all these publications the topic is approached from the negative standpoint; that is, what made the water taste or smell bad. This is even more pronounced in the case of organic constituents. Also, the analytical methods used to identify organic constituents are generally quite crude, the instrumentation often being a "chemist's" nose.

Some authorities state that "public water supplies should be of such palatability that they produce no sensation of either taste or odor." (2) This philosophy is not agreeable with our findings especially for spacecraft use, and furthermore, the absence of any taste and/or odor does, in fact, render the water less palatable. It is noted that it is possible for waters to possess taste without odor even though the presence of odors always gives rise to complaints of taste. Tastes without odor are usually due to the presence of certain mineral or saline constituents. NaCl and Na_2SO_4 impart saline taste. Fe, Mn, Zn, excess of free lime $Ca(OH)_2$, and Al compounds produce an astringent (equated to bitter or metallic) taste. Cu in excess of 1 ppm may impart a disagreeable taste.

The temperature of the water will have a pronounced effect on palatability,

since both solubility and volatility are strong functions of temperature.

Certain waters also have an action on the palate which could not be

described as either taste or odor. Chalk-derived waters, for example,

are reported to possess a "sharpness" or pleasant palatability, probably due

to the presence of CO_2 and $CaHCO_3$. On the other hand, waters derived from

surface sources and waters which are very soft or are deficient in oxygen

are often described as flat or insipid. This would indicate dissolved

gases play an important role in palatability. Organic contamination in

public water supplies produces tastes and odors described as musty, earthy,

weedy or moldy. Algae, protozoa, actinomycetes and other microorganisms

produce tastes and odors described as musty, earthy, fishy, aromatic, etc.

and are often accentuated by chlorine. One author states the most palatable

waters are those containing nitrates and free CO_2, even though they may have

been derived by degradation of objectionable microorganisms.

In summary it can be stated that the presence of taste and odor in

water supplies is due to one or a combination of the following:

(1)   Presence of dissolved gases (H_2S, CO_2, O_2, etc.)

(2)   Contamination by contact with improperly prepared surfaces

(3)   Contamination by organic matter from sewage, manure, soil and
      vegetation

(4)   Contamination by chemicals such as industrial wastes

(5)   Growth of algae, protozoa, fungi, etc.

(6)   Treatment processes applied, e.g., chlorination, filtration, etc.

2.3 Water Analysis Methods

Our interest in water analysis methods was threefold. First, we wanted to select the best methods for subsequent analysis of palatability. Secondly, we wanted to evaluate methods for their potential in spacecraft water quality monitoring; and finally, we hoped that the literature would have mentioned palatability even though it did not appear in key phrases. (About twenty papers on water regenerating systems were also read with the latter in mind). We were particularly interested in organic compounds, both volatile and nonvolatile. Thirty-one papers were examined of which two were general reviews and are listed in the bibliography (5-30). The most pertinent of these is the review (6) published in Analytical Chemistry in 1971 which covers the following constituents: Alkali metals; Al, Fe, Mn, Cr, Os, and Re; Cu, Zn, Pb, Cd, Ni, Co, Ge, and In; Hg, Ag and Au; Va, Zi, Wg, Mo, Sc, U, and rare earths; Cl^-, Br^- and I^-; B, Se, As and Sb; fluoride; phosphorous and silica; nitrate, nitrite and nitrogen compounds; pH and alkalinity; oxygen demand; oxygen and other dissolved gases; detergents, pesticides and herbicides; organics; and radioactivity and isotopic analysis. With the exception of the organics, the methods reviewed are adequate for all constituents that may be of importance in palatability considerations. The methods cited for organic compounds are for dissolved material in microgram quantities and, therefore, are not sufficiently sensitive (odor sensations are produced by 10^{-14} g quantities).

Several of these papers (15-30) deal with the analysis of headspace volatiles above pure compounds, aqueous solutions and foods, and volatile organics in room air. These methods were of interest to compare to our

proposed headspace analysis technique for organic volatiles in water. The methods found in the literature exhibited one or more of the following deficiencies: (1) low sensitivity because of lack of any concentration step, (2) requiring analysis times of 24-72 hours, and (3) incomplete separation of the complex organic mixture contained in the sample.

2.4 Water Standards

Water quality standards have been developed over the years for public drinking water with the primary purpose of minimizing toxicity problems which could arise in uncontrolled water supplies. Secondary considerations have included a desire to produce an attractive (equated to colorless) and palatable (no undesirable taste or odor) water so as to discourage the use by the public of other water supplies which are not safe. In the past fifteen years many different types of engineering devices have been developed in the space program to produce water from human waste, chamber atmosphere, and O_2-H_2 fuel cells. This has led to the generation of a set of aerospace potable water standards which in some degree take into account the special problems associated with reclaimed water. Table 1 lists the International, USPHS, American Water Works Association, and recommended (Slonim et al, 1967) aerospace water standards for comparison purposes. The aerospace water standards are higher values in general for chemical consitutents which can be justified by the short (compared to a normal life span) exposure to such water. It is possible that many of these chemicals could be eliminated from spacecraft water potability criteria if certain materials are not present in the spacecraft water system, and thereby eliminate many monitoring requirements. On the

TABLE 1

Comparison of Water Standards

Water Quality Criteria	International	Public Health Service	AWWA[1]	Aerospace
BIOLOGICAL				
Coliform organisms/100 ml	10[2]; 1.0[3]	1.0	0.1	None
Coliform organisms, total count	No limit	No requirement	No requirement	None
Micro organisms	No requirement	No requirement	0	200/ml
Viruses	No requirement	No requirement	No requirement	No requirement
PHYSICAL				
Color, cobalt scale units	5	15	3	15
Odor (threshold no.)	Unobjectionable	Inoffensive[4]	No requirement	3
Taste (threshold no.)	Unobjectionable	Inoffensive	None	3
Turbidity, silica scale units	5	5	0.1	25
CHEMICAL[5]				
Alkyl benzene sulfonate	0.5	0.5[6]	0.2	None
Aluminum	No requirement	No requirement	0.05	No requirement
Arsenic	0.05	0.01[6] 0.05[7]	0.01	0.5
Barium	1.0[8]	1.0[7]	0.5	2.0

TABLE 1 (CONT'D)
-2-

Water Quality Criteria	International	Public Health Service	AWWA[1]	Aerospace
CHEMICAL[5] (cont'd)				
Cadmium	0.01[8]	0.01[7]	0.01	0.05
Calcium	75	No requirement	No requirement	No requirement
Calcium carbonate[9]	No requirement	No requirement	86	No requirement
Carbon alcohol extract	No requirement	No requirement	0.1	No requirement
Carbon chloroform ex.	0.2	0.2[6]	0.04	100[13]
Chloride	200	250[6]	No requirement	450
Chromium, hexavalent	0.05[8]	0.05[7]	0.01	0.05
Copper	1.0	1.0[7]	0.2	3.0
Cyanide	0.2[8]	0.01[6] 0.2[7]	0.01	No requirement
Fluoride	1.0-1.5	0.8-1.7 1.4-2.4	0.7-1.2	2.0
Hydrogen ion (pH)	7.0-8.5	No requirement	No requirement	5.0-10.0
Iron	0.3	0.3[6]	0.05	1.0
Lead	0.05[8]	0.05[7]	0.05	0.2
Magnesium	50	No requirement	No requirement	No requirement
Magnesium + sodium sulfate	500	No requirement	No requirement	No requirement
Manganese	0.1	0.05[6]	0.01	0.1
Nitrate	45	45	23	100
Phenol	0.001	0.001[6]	0.0005	0.05
Selenium	0.01[8]	0.01[7]	0.1	0.05
Silver	No requirement	0.05[7]	0.02	0.5
Sulfate	200	250	No requirement	250
Zinc	5.0	5.0[6]	1.0	15
Total dissolved solids	500	500	No requirement	1000[12]

TABLE 1 (CONT'D)
-3-

Water Quality Criteria	International	Public Health Service	AWWA[1]	Aerospace
RADIOCHEMICAL				
Strontium-90	30	10[11]	5	10
Radium-226	10	3[11]	3	3
Gross beta	1000	1000[11]	100	1000
Reference	(C)	(B)	(A)	(D)

REFERENCES AND FOOTNOTES

(A) American Water Works Association. 1967. Willing Water 11(6).

(B) U.S. Public Health Service. 1962. U.S. Public Health Service P. 956

(C) World Health Organization. 1963. International standards for drinking water. Columbia University Press: New York.

(D) Slonim, A. J. et al, Aerospace Medicine, 38, pp. 793-799, 1967.
     1. Criteria are tentative. 2. In 90% of the samples untreated water examined in any one year. 3. In treated water. 4. Maximum threshold number, 3. 5. Values are ppm, except the value for pH. 6. Recommended. 7. Mandatory limit. 8. Tolerance limit, comparable to the mandatory limit of the Public Health Service standards. 9. Criterion for hardness. 10. Values are c/liter. 11. For full interpretation, consult 1962 Public Health Service Drinking-Water Standards. 12. Total solids. 13. Chemical oxygen demand-COD.

other hand, certain constituents might have to be added because of the nature of the system.

Although the aerospace standards in Table 1 contain limits for taste, odor, phenol, dissolved solids, and micro-organisms, they do not adequately consider palatability and are primarily based on toxicity. Phenolic compounds are present infrequently and have probably been overemphasized because they are one of the few materials detectable by analytical techniques generally available in water plant laboratories. Before chlorination, commonly occuring phenolic materials have little taste or odor. Other treatments can destroy the odor. The inclusion of values for dissolved gases deserves careful consideration. Furthermore, one can index organic content in several ways: BOD, COD, DOC (dissolved organic carbon), organic nitrogen, etc. are examples of group methods. This group treatment, however, is not sufficient for palatability considerations and individual taste and odor producing components indices must be derived. These individual components will be those known to be associated with a particular water supply (whether it be storage or regenerative), which also cause a significant organoleptic response.

2.5 Psychological Aspects in Water Quality Development

In a concept of regenerated water quality development, the establishment of potability and palatability criteria must be reviewed in terms of psychological barriers toward consumer acceptance. The consumers' awareness of the technologies involved in the production of the product water is as significant as the maintenance of qualities such as odor, taste, turbidity, toxicity, etc. It is, then, important in the development of new

methods of closed-ecological water regenerating systems that a simultaneous educational effort be undertaken in order to overcome obvious psychological barriers for acceptance. Educating the user in the principles of hydro-chemistry and the reclaiming process can be helpful. The increased effort required to monitor the physical, chemical, and biological properties of the regenerated water should also be pointed out.

2.6 Palatability Related Factors

General considerations for potable and palatable water include (a) toxicity; (b) mineral constituents, dissolved gases, dissolved (nonvolatile) organic compounds, and volatile organic compounds affecting taste and/or odor; (c) color producing material; (d) total solids; (e) psychological factors; and (f) physiological factors. Specifications for inorganic and organic components related to toxicity considerations may (1) exclude or reduce the amount of those in USPHS criteria because of short exposure (e.g., ABS, As, Ba, Cd, Cr, F, Pb, Zn, Mn, Se) (2) add additional components or amounts because of the peculiarities of the particular storage or regenerative system supply (e.g., Be, B, Hg, V, Sb, Cs, I, Li, Pt and unknown urine volatile organics).

Our laboratory investigations and many of the references in the bibli-ography (11-15, 25, 27, 28, 30, 31) make it clear that extemely small amounts of odorous materials can cause sensory stimulation. Experiments have frequently yielded a detectable odor from recovered materials in concentration of 2 ppb and less. Sometimes materials have been isolated which could be detected by odor in concentrations less than 0.01 ppb. Utilizing adsorption and extraction techniques for concentrating odorous

organic constituents of drinking water supplies, it has been found that
neutral compounds are usually the most abundant odorous organics present.
These neutral organic materials usually have intense tastes and odors.
The second most abundant group of odorous materials is usually the
organic acids, which also have intense odors and tastes. Small quantities
of other materials have been recovered, including organic bases (which may
have a tobacco-like odor), water soluble compounds (which frequently have a
carmel-like odor), and a group usually referred to as the weak acids which
include phenolic compounds, if they are present in water.

The references to palatability found in the literature are generally
negative. That is, chemical constituents which give rise only to undesirable
tastes and odors are described. Table 2 summarizes the negative and positive
(enhancement) factors related to palatability. Many other anions, cations,
and dissolved gases are known to have negative effects on palatability,
but those listed are most often encountered.

Based on the above, the first consideration in the production of
taste enhanced potable water is the removal of all mineral constituents,
volatile odor compounds, color producing material and microorganisms.
Various methods are available including ion exchange, membrane filtering,
vapor pyrolysis, and distillation; but the starting material should be
equivalent to a quadruply distilled water. Taste producing compounds can
then be added to the water to give the desired taste enhancement.

The taste of water is affected by the common dissolved minerals:
calcium, magnesium, potassium, sodium, bicarbonate, carbonate, chloride,
fluoride, nitrate, and sulfate. Complete removal of these minerals

TABLE 2

PALATABILITY   RELATED   FACTORS

NEGATIVE   FACTORS

ENHANCEMENT   FACTORS

INORGANIC ANIONS AND CATIONS

$NaCl$, Na_2SO_4 ——————→ SALTY TASTE > 250 PPM

Fe, Mn, Zn, $Ca(OH)_2$, Al ——→ BITTER OR METALLIC TASTE 10-50 PPM

Cu ——————————→ DISAGREEABLE TASTE 1 PPM

Ca^{++}, Mg^{++}, K^{+}, Na^{+}

HCO_3^{-}, $CO_3^{=}$, Cl^{-}, F^{-}, NO_3^{-}, $SO_4^{=}$

DISSOLVED GASES

AMMONIA (NH_3) AND HYDROGEN SULFIDE (H_2S)

O_2, CO_2 AND PERHAPS N_2

ORGANIC COMPOUNDS

CERTAIN ACIDS, IMIDES, AMIDES, AMINES, PHENOLS

BUT NO INFORMATION ON VOLATILE ORGANICS

SOME ALCOHOLS, ACIDS, AND SUGARS BUT

NOTHING REPORTED ON VOLATILE COMPOUNDS

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produces a flat, bitter tasting water. A certain amount of each of these minerals should be added back to produce a water with approximately 100 to 150 ppm total dissolved solids. A Russian worker (44) has also observed a possible negative physiological reaction in human subjects consuming water lacking these chemical components, (especially calcium and fluoride), but otherwise on a normal diet. This would indicate there are also physiological reasons for adding back these minerals. The optimum concentration of these minerals can only be determined by detailed taste panel evaluations of chemically analyzed test waters.

It appears that dissolved gases (O_2, CO_2 and perhaps N_2) should also be added back to the water. It is difficult to estimate values at this time, but the range 1-5 ppm O_2 found in natural waters can be a starting point. Final values here again must be determined by taste trials.

3.0 EXPERIMENTAL APPROACH

Several water samples, including product waters from prototype water reclamation systems, were evaluated for taste and chemically analyzed for the constituents listed in Table 2 which were those deemed most essential for good tasting potable water. This included analyses for anions, cations, acidity, pH, NH_3, dissolved gases, total organic carbon, particulate organic carbon, dissolved organic carbon, and volatile organic qualitative profiles. The procedures used for these analyses are described in the analytical methods section.

The quantification of individual volatile organic components was attempted utilizing the same solid adsorbent trapping and analysis technique used for qualitative volatile organic profiles. The technique was modified somewhat to optimize quantification of nanogram amounts. Methods of preparing standards and a description of the detailed quantitative procedures are given.

Synthetic water samples were fabricated by adding chemicals to specially prepared ultraclean water for palatability tests by a taste panel. Preparation of these samples and procedures for tasting are described.

3.1 Analytical Methods

3.1.1 Inorganic, Dissolved Gases and Organic Carbon

Reference to the 13th Edition (1971), Standard Methods for the Examination of Water and Wastewater is made for the following: dissolved CO_2, sulfates, ammonia - N_2 and fluorides. A Fisher pH meter was used for pH measurements; dissolved oxygen was determined on a

Weston-Stack Analyser and a Beckman Carbonaceous Analyser was used for total organic carbon, particulate organic carbon, dissolved organic carbon and total inorganic carbon. Ca^{++}, Mg^{++}, K^+, and Na^+ were run by atomic absorption spectroscopy according to the procedures in Water Analysis by Atomic Absorption Spectroscopy, by C. R. Parker, Varian Techron Pty. Ltd. Springvale, Australia (1972).

3.1.2 Qualitative Volatile Organic Profiles

Volatile organic compounds in the water samples were collected on a solid adsorbent trap by a headspace sampling technique. Figure 1 shows a cross sectional view of the trap and the modified gas chromatograph injector port which is used to desorb the trap. The adsorbent was Tenax GC 35/60 mesh (supplied by Applied Sciences, Inc., State College, PA). Figure 2A shows a diagram of the sampling apparatus. The liquid is placed in a 100°C water bath and the headspace swept with helium at 20 ml/min for approximately one hour. Sample sizes of 200 ml were extracted in this manner. Volatilization was increased by the addition of $(NH_4)_2SO_4$ (30% w/v). The trapped sample was then stored in a clean teflon lined screw cap sealed Pyrex vial for subsequent analysis. The purge gas and volatiles are passed through a short water condenser prior to introduction to the adsorbent trap.

The analysis was begun by removing the trap from the storage tube and inserting it into the modified injector port (Figure 1) of a Perkin-Elmer 900 gas chromatograph. The sample was thermally desorbed for 20 minutes into a dry ice cooled capillary pre column (10' x .02" i.d.) (Figure 2B). After the allotted transfer time, the coolant was removed

FIGURE 1

TENAX TRAP AND INJECTOR PORT

MODIFIED INJECTOR PORT
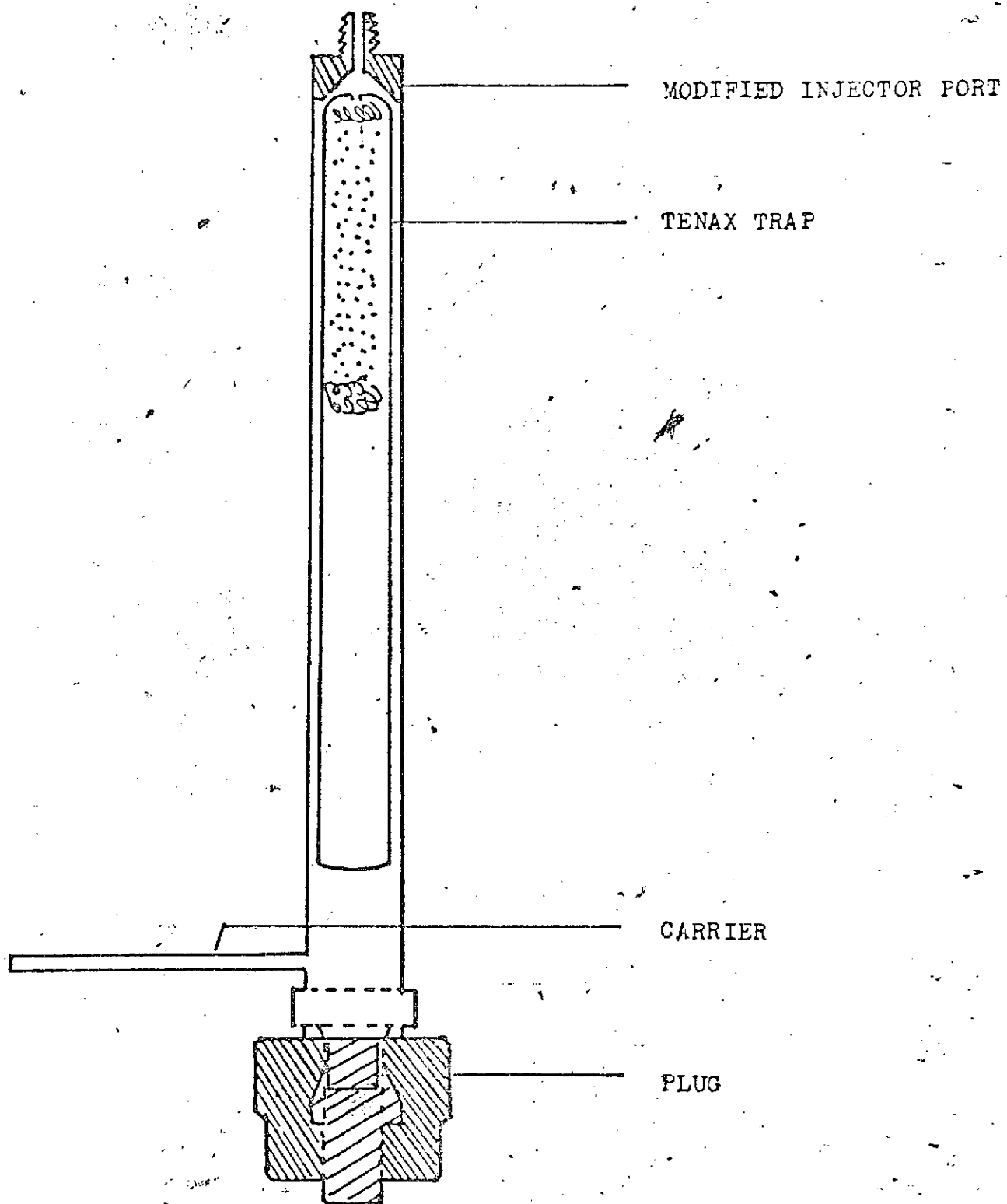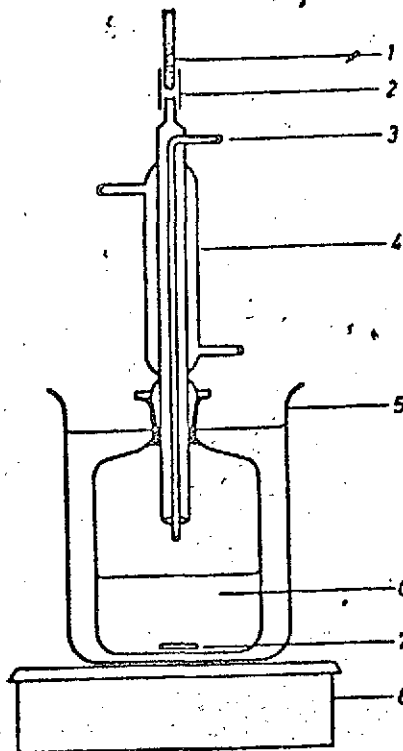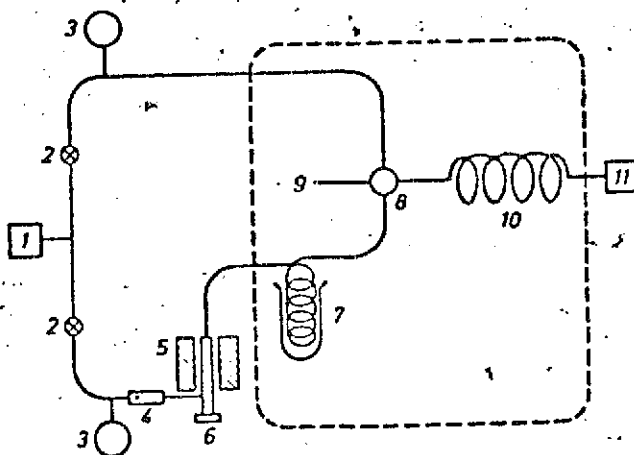
TENAX TRAP

CARRIER

PLUG

FIGURE 2

2A

● Aqueous Volatile Sampler

1 Trap-insert with Tenax-GC, 2 Teflon sleeve, 3 Helium inlet,
4 Condenser, 5 Boiling water bath, 6 Sample, 7 Magnetic stirring
bar, 8 Hot-plate-stirrer

2B

● Sample Analysis and Transfer Flow System

1 Carrier (He)	6 Modified injector port
2 Toggle switch	7 Pre-Column in dry ice
3 Pressure regulator	8 4-port valve
4 Rotameter	9 Vent
5 Injector block	10 Separating column
	11 Detector

from the pre column and a four port valve (Valco Instruments, Houston, Texas),
allowing simultaneous carrier flow to the pre column (20 cc/min) and
separating column (3 cc/min), was turned. This diverted the sample in the
pre column to the separating column to begin the chromatographic separation.

A Perkin-Elmer 900 gas chromatograph (Flame ionization detector) was
used for qualitative GC profiles and the injector and detector temperatures
were 200°C and 280°C, respectively.

An LKB 9000 combination gas chromatograph-mass spectrometer (LKB-Pro-
dukter AB, Bromma, Sweden) was used for identification of significant
compounds in the water samples. Sampling, trapping, and GLC conditions
were similar to those used on the Perkin-Elmer 900 except the pre column
was connected to the separating column manually. The ion source and separa-
tor temperatures were 250°C and 220°C, respectively. Analyses were made
at 70 eV electron energy. Scanning rate was 4.5 seconds over the mass
range 20-350.

3.1.3 Quantitation of Volatile Organics

A primary standard at a concentration of 1,250 milligrams
per liter (ppm) in water was made for the compounds to be examined.
Secondary standards of 50 micrograms per liter (ppb) in water were made by
dilution. Fifty milliliters of these secondary standards, representing
a total of 2.5×10^{-6} grams of each compound were used for Tenax sampling.

The glassware and Texas traps used were described in the previous
section. Glassware was cleaned initially in No-Chromix, sulfuric acid and
then rinsed with deionized water and oven dried. The trapping system was
assembled and purged with prepurified N_2 passed over Carbosieve B. Fifty

milliliters of the water to be sampled was added to the flask and the flask heated by means of a boiling water bath. The sample was stirred with a magnetic stirring bar and the surface swept at a rate of 20 milliliters per minute with the prepurified N_2. Initial recoveries were poor (see results section) and refluxing was substituted for this step. The headspace gases were swept through a water condenser prior to entering the Texas trap.

After sampling for 1 hour, the trap was removed and stored in a teflon lined screw cap test tube. The sample was transferred to a dry ice cooled pre column (10' x .05" i.d., ss., coated with DC-200) by placing in a modified injector port and heating for 20 minutes at 200°C, while passing helium gas through the trap and pre column at 20 milliliters per minute. At the end of the desorption period, the pre column was placed in series with an analytical column by means of an eight port switching valve and then flash heated. Gas liquid chromatography was performed on a 5' x 1/8" o.d., s.s. column packed with 5% DC-200, 0.5% Carbowax, 20 M on 100/140 mesh Chromosorb W-HMDS. The temperature was isothermal at 30° C for 2 minutes then programmed to 200°C at 8°C per minute. Carrier gas was helium at 25 milliliters per minute and a flame ionization detector was used.

3.2 Preparation of Synthetic Water Samples for Taste Evaluation

Ultrapure pure water was prepared from deionized water by distillation with potassium permanganate in a 43 cm glass fractionating column and stored at 40°F. Atomic absorption analyses showed calcium, magnesium, potassium, and sodium to be present at less than 0.1 ppm each. Volatile organics in the ultrapure water were determined using the Tenax solid adsorbent trapping procedure described in the previous section. A blank

run was made on the cleaned empty apparatus and subtracted from the water
sample. The net area of all peaks was multiplied by a calibration factor
determined by direct injection of C_8 and C_{12} hydrocarbons. The results
indicated the purified water contained less than 0.2 ppb total volatile
organics. Calcium and magnesium ions were added as sulfates and potassium
and sodium ions as chlorides to produce water samples with the desired
concentrations for taste evaluation.

4.0 EXPERIMENTAL RESULTS AND DISCUSSION

　　4.1 Evaluation of Waste Water Reclamation Systems

　　　　Product water samples and starting materials from several proto-
type reclamation systems were chemically analyzed and tasted. Addition-
ally a commercial bottled water, distilled water, and tap water were
analyzed and tasted for comparison.

　　　　4.1.1 Inorganic Chemical Constituents, Dissolved Gases and

　　　　　　　 Organic Carbon

　　　　　　　 Four different water samples including two samples from
water reclamation pilot systems (Skylab and SWRI), a sample of synthetic
water supposedly equivalent to spring water (Foremost) and Houston tap
water were analyzed. These analyses included only those factors which
we considered most important to palatability (see Table 2). The results
of these analyses are given in Table 3. Values for all factors were not
obtained for the SWRI sample because of lack of sufficient sample. The
relative palatability or taste of the samples was determined by a single
taster and is also given (1 is the best tasting water).

　　　　The anion and cation values for the Skylab and SWRI samples are very
low, as they should be since the reclamation process is intended to
remove them. The Foremost sample was also processed to remove all cations
and anions, but Ca^{++}, Mg^{++}, K^+ and Na^+ were added back to the processed
water to enhance the taste. The high Cl^- and $SO_4^=$ result from the addition
of the cations as the Cl^- and $SO_4^=$ salts. The organic carbon values are
quite high for the SWRI sample. Possible sources of this carbon are
discussed in the next section.

TABLE 3

W A T E R   A N A L Y S E S   R E S U L T S

	SKYLAB		SWRI		FOREMOST		TAP WATER	
Ca^{++}	< 1	ppm	< 1	ppm	40	ppm	29	ppm
Mg^{++}	< 0.1	ppm	< 0.1	ppm	9.6	ppm	6.2	ppm
K^{+}	< 1	ppm	< 1	ppm	1.3	ppm	97*	ppm
Na^{+}	< 1	ppm	< 1	ppm	10	ppm		
ACIDITY (as $CaCO_3$)	27	ppm	19	ppm	4	ppm	22	ppm
Cl^{-}	7	ppm	9	ppm	82	ppm	53	ppm
F^{-}	0.4	ppm	——		1.7	ppm	0.6	ppm
NO_3^{-}	< 0.1	ppm	——		< 0.1	ppm		
$SO_4^{=}$	5	ppm	< 5	ppm	45	ppm	6	ppm
$HCO_3^{-} + CO_3^{=}$	< 1	ppm	< 1	ppm	< 1	ppm	276	ppm
pH	3.7	ppm	4.5	ppm	4.7	ppm	7.8	ppm
NH_3	< 0.02	ppm	——		< 0.02	ppm	< 0.02	ppm
DISSOLVED O_2	3.8	ppm	4.5	ppm	3.0	ppm	5.2	ppm
DISSOLVED CO_2	< 1	ppm	< 1	ppm	< 1	ppm	< 1	ppm
TOC (Total organic carbon)	1	ppm	23	ppm	< 1	ppm	< 1	ppm
POC (Particulate organic carbon)	0	ppm	1	ppm	0	ppm	0	ppm
DOC (Dissolved organic carbon)	1	ppm	22	ppm	< 1	ppm	< 1	ppm
RELATIVE PALATABILITY	3		3		1		2	ppm

*$K^{+} + Na^{+}$

24

It can be seen that the better tasting sample (Foremost) is also the sample which better fits the criteria for palatability (see section 5.0). One could speculate that the high organic carbon content of the SWRI sample may have been responsible for the lower relative palatability of this sample, but the lack of important (to palatability) cations and anions may also be an important factor.

4.1.2 Volatile Organic Profiles

A first step in obtaining waste material contaminants is the determination of volatile organic compounds, because of the high probability of their presence in product water of some reclamation systems (e.g., distillation). Over two hundred volatile organic compounds in human urine have been concentrated, and analyzed by high resolution gas chromatography and at least eighty (80) of these compounds have been identified by combined gas chromatography-mass spectrometry (GC-MS). There is good indication that many of these eighty compounds are indigenous to all human urine. Therefore, in the chemical evolution of waste water reclamation systems, the quality of product water may be more adequately described in terms of efficiency of removal and origin of contamination.

Prior to sampling product water and its starting materials, system blanks and controls were undertaken. Figure 3A represents a chromatographic analysis of a conditioned Tenax trap desorbed and cryogenically transferred to the chromatographic column. Since no sample was passed over the adsorbent, any ensuing peaks would have arisen in the sampling and analytical system. Figure 3B represents the analysis of approximately 30 grams of $(NH_4)_2SO_4$ used as a salting out agent. Figure 3C depicts a deionized water
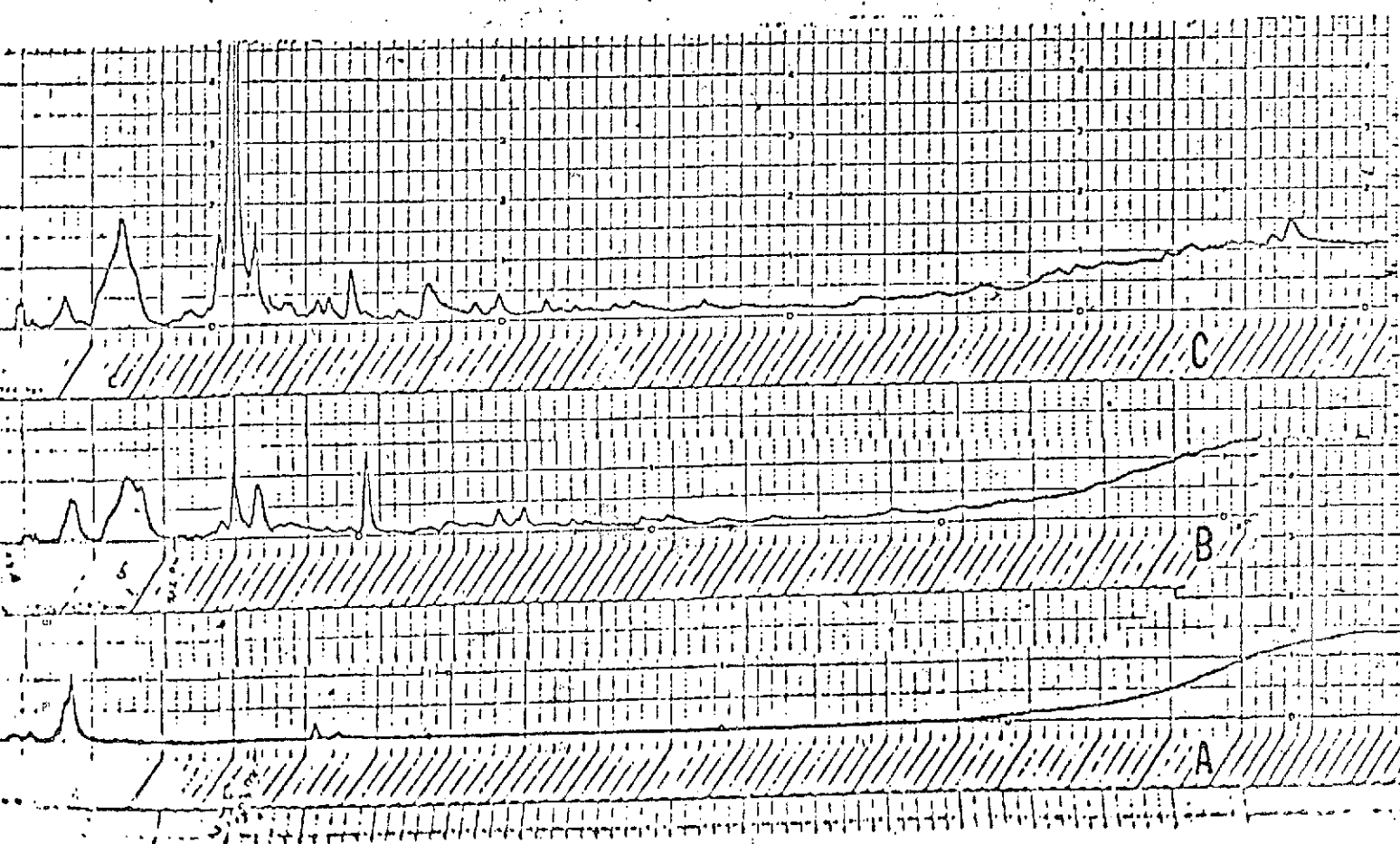
FIGURE 3

VOLATILE ORGANIC PROFILES - CONTROLS

A. Tenax GC - blank

B. $(NH_4)_2SO_4$ - blank

C. Deionized water - control

D. Distilled water - control

E. Houston, Texas ground water

→X40

E

→X40

D

C

B

A
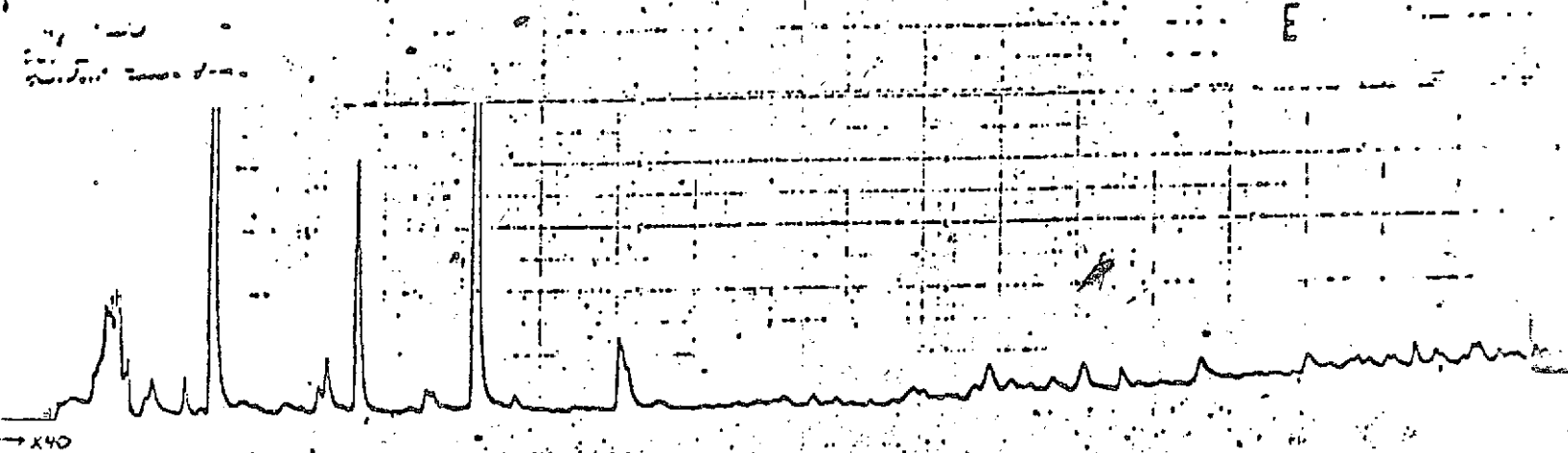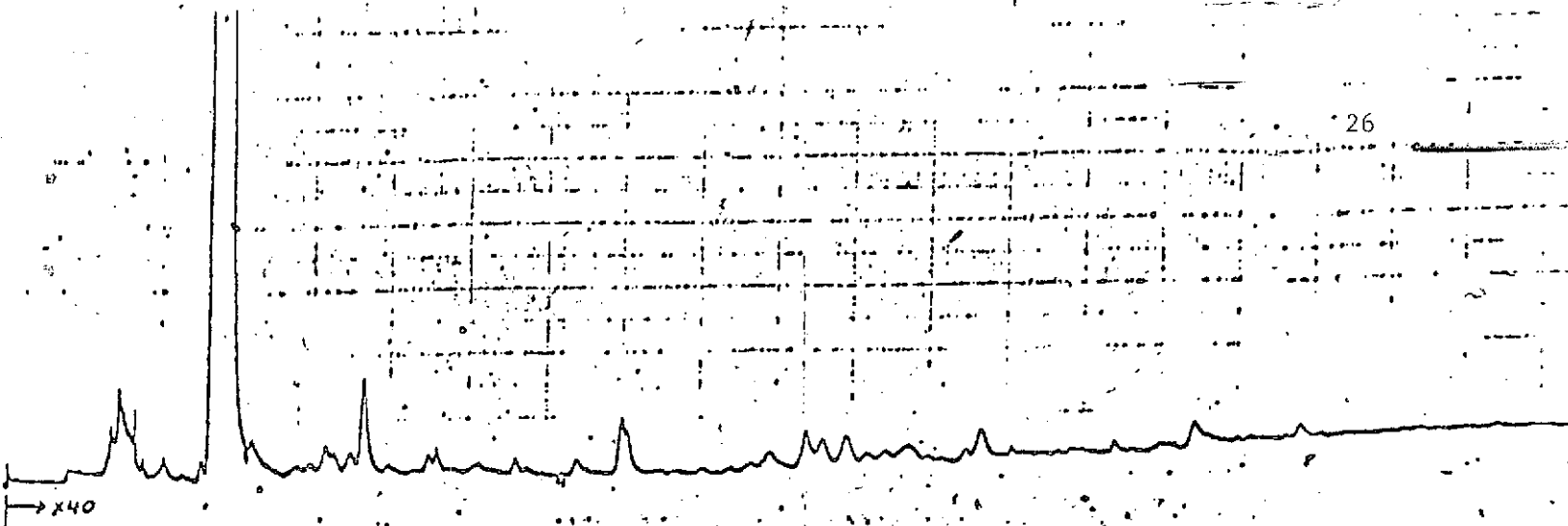
sample, containing 30% $(NH_4)_2SO_4$ as all future aqueous samples do. Figures 3D and 3E respectively represent distilled and Houston, Texas ground water.

The first product water sample examined in a preliminary analysis was from Chemtric Corporation. Figures 4A and 4B compare the product water and a Houston ground water sample. The striking difference in volatile organic profiles can not be explained in terms of the origin of these organics, since no starting material (urine) was available for comparison.

The first gas chromatographic-mass spectrometric analyses were run on a product water from a General Electric -AEC system using radioisotopes for thermal energy (RITE). The GE-RITE analysis is shown in Figure 5. The similarity of this sample and the Chemtric sample may be accounted for in part if urine were a starting material. For example, a list of volatile organics found in the GE-RITE sample (Table 4) indicate that some of these compounds have been found in human urine.

Figure 6 represents the analysis of a commercially bottled water (Foremost), and several major peaks have been identified by gas chromatography-mass spectrometry (Table 4); however, the origin of these compounds is not known. Table 4 also gives the relative total volatile organics found in these samples compared to the Houston ground (tap) water. It can be seen that these values do correlate with taste, the poorer tasting waters being higher. Based on the dissolved organic contents given in Table 3 the upper limit of volatile organics in the poor tasting Skylab water sample is 1 ppm or 1000 ppb. This can then be taken as a maximum allowable limit for the total volatile organics. Individual components may

FIGURE 4

VOLATILE ORGANIC PROFILES IN A POTABLE WATER SYSTEM

A. Regenerated Water System - Chemtric Corporation

B. Houston, Texas ground water

A

B

30   60   90
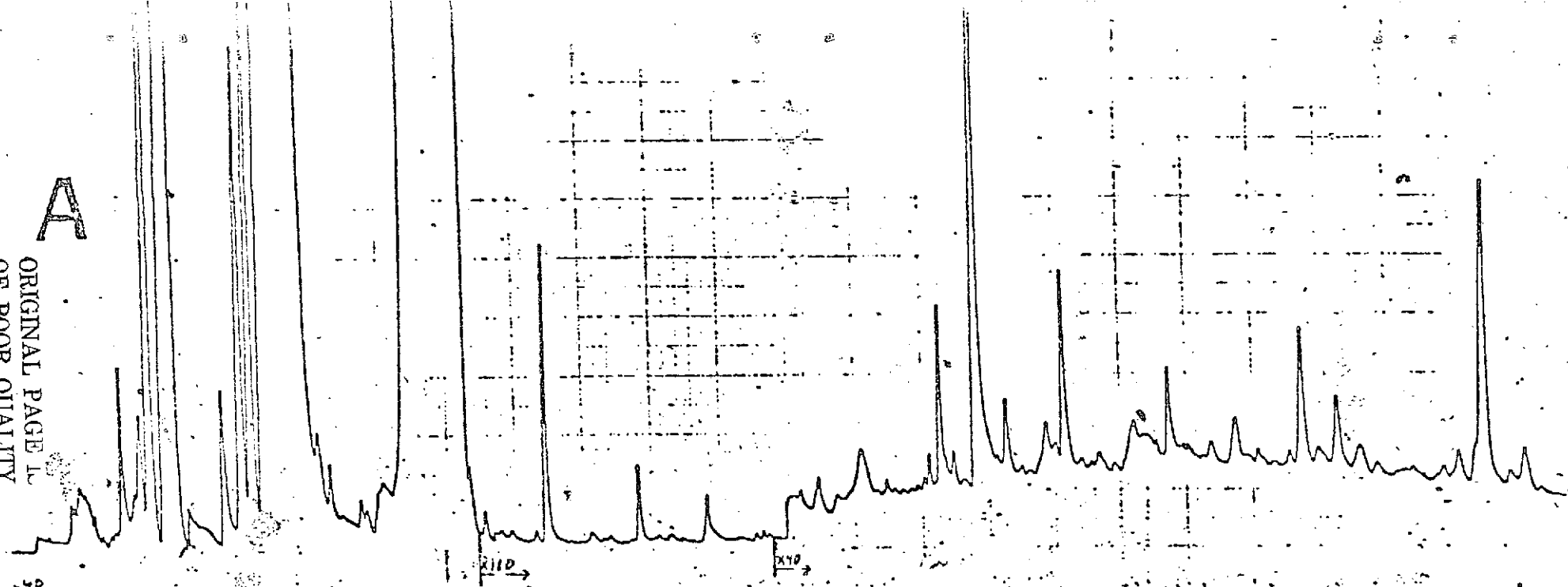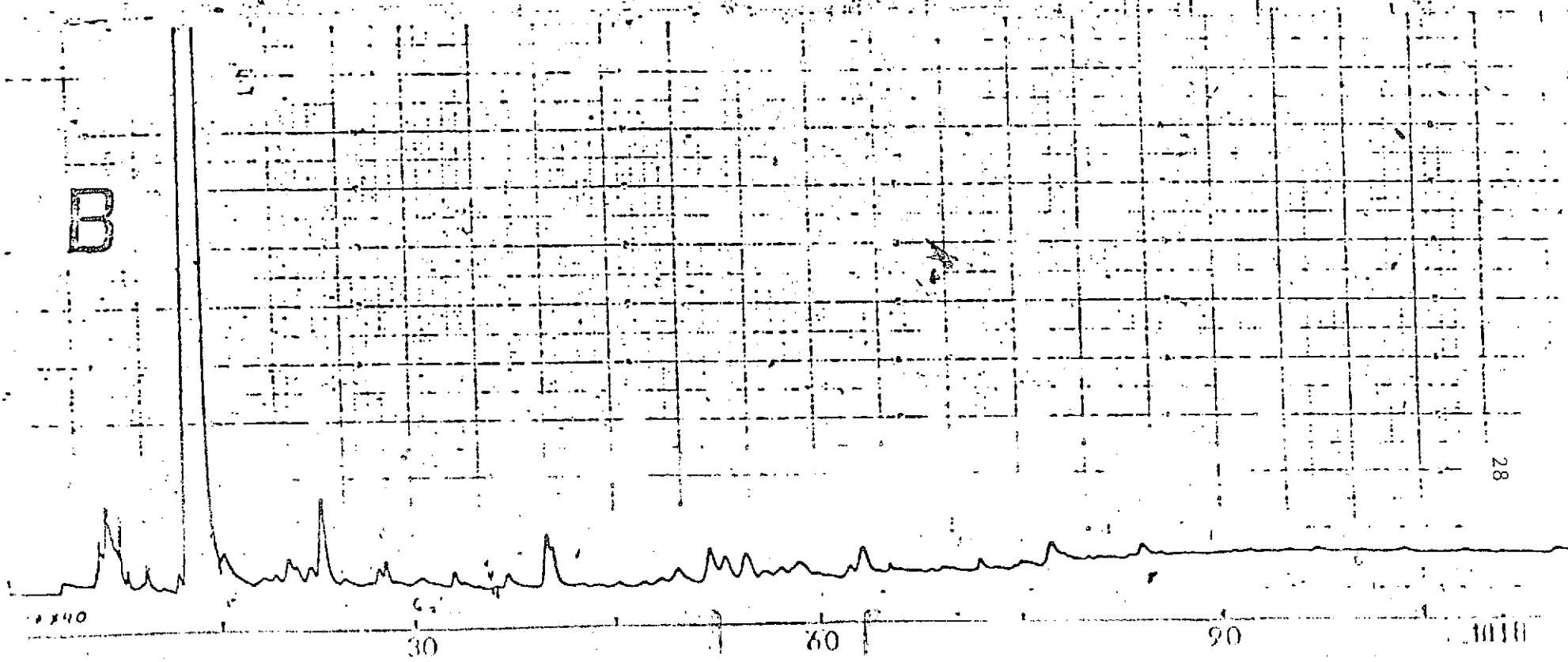
FIGURE 5

VOLATILE ORGANIC COMPOUNDS IN A REGENERATED

WATER SYSTEM (GE-RITE)

25   80   80   80   110   60   170   50   min °C

29
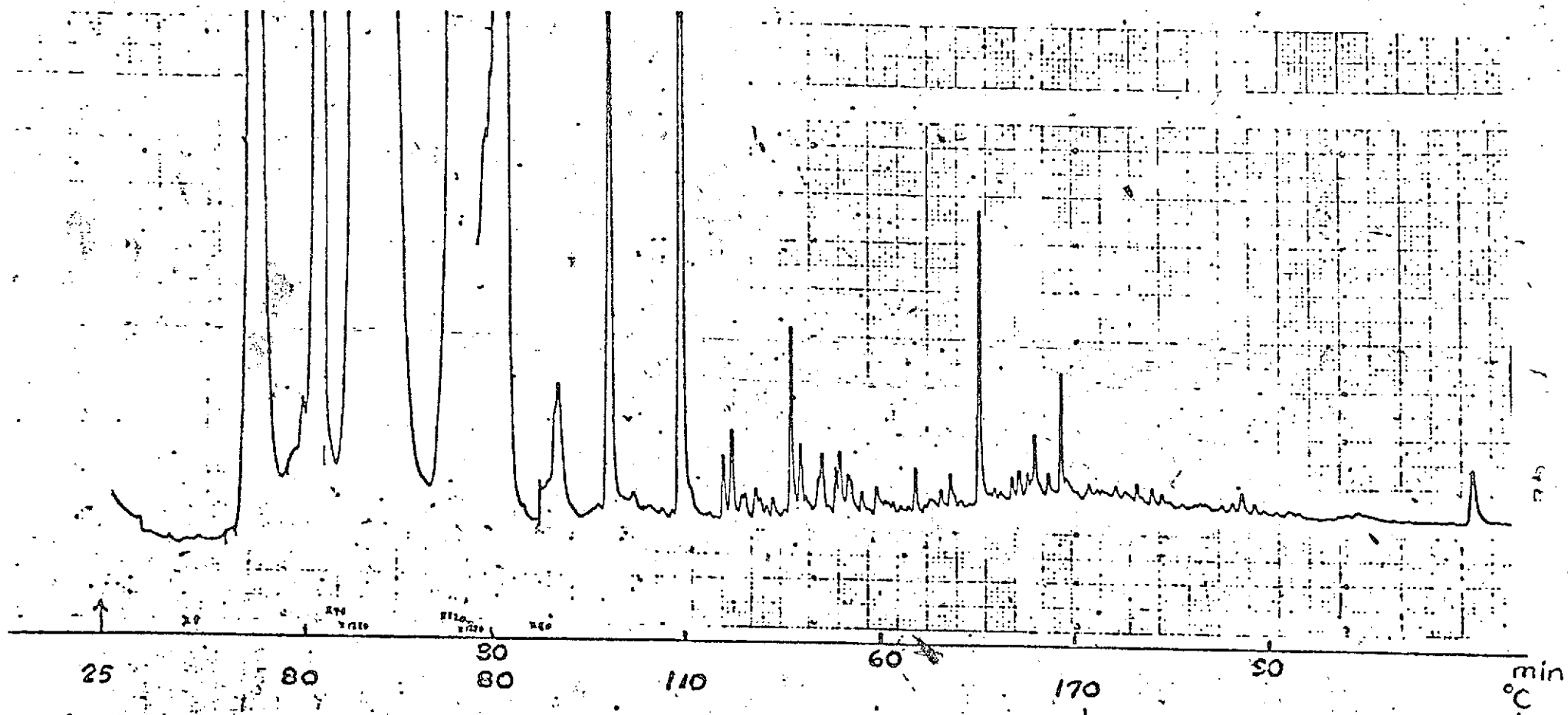
TABLE 4

VOLATILE ORGANICS*

IN POTABLE WATER

SKYLAB	GE	SWRI	FOREMOST
	Acetone**		
	2-Butanol**		
Undecane	Benzene	High MW's	Dichloromethane
	Pentanone**		Benzene
Cyclohexane	Dioxane	Dioxane	Undecane
	Isopropanol**	2-Methyl-1,3 dioxalane	
Silicones	Toluene		Naphthalene
	Diethylsulfide**		
Dodecane	$n-C_{10}$		
	Propanol**		
	Methyl propanol		
	3-methyl-1-butanol		
	$n-C_{11}$		
	Trimethyl benzene		

TOTAL VOLATILE ORGANIC CONTENT RELATIVE TO TAP WATER			
100	10,000	100	10

*in order of elution   **previously found in human urine

FIGURE 6

VOLATILE ORGANIC PROFILE OF A COMMERCIALLY

AVAILABLE BOTTLED WATER (FOREMOST)

31
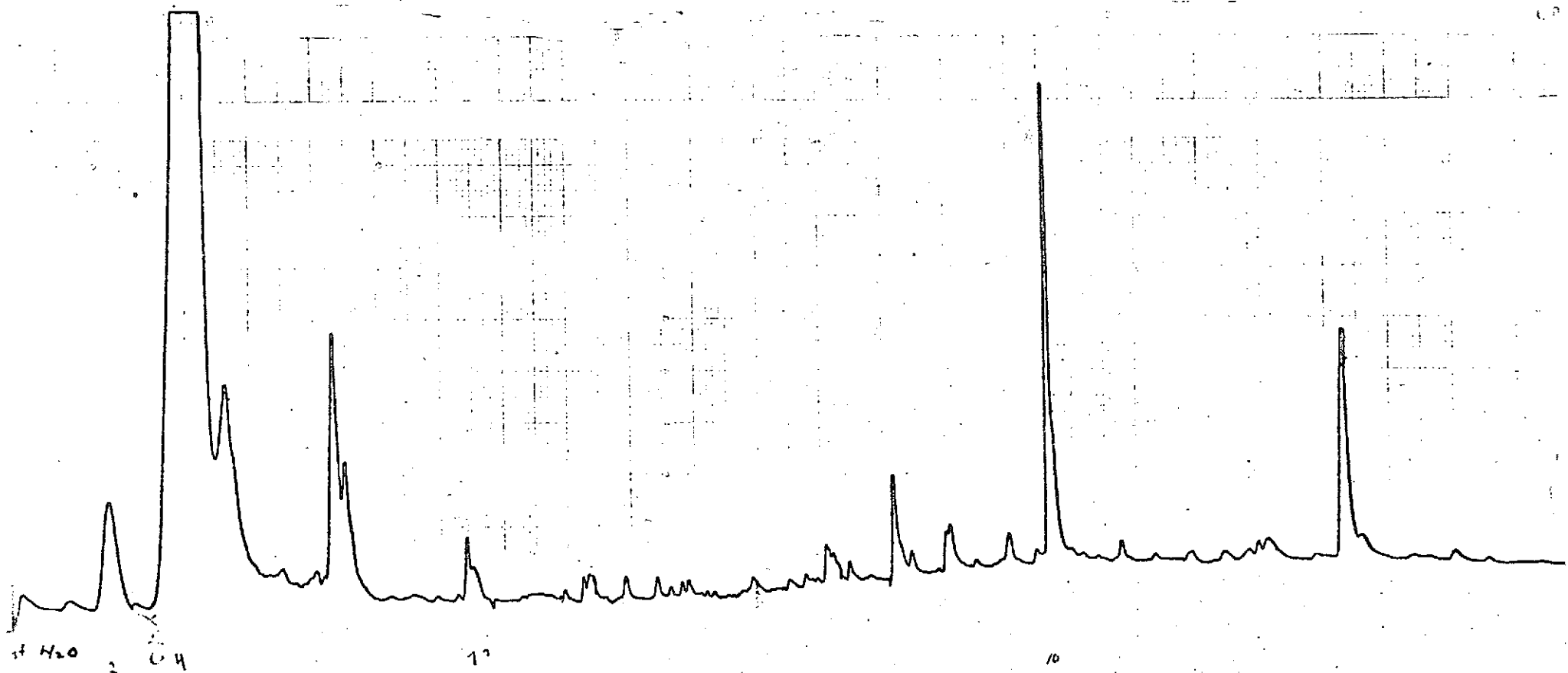
require control to 1-10 ppb levels, however, depending on their odor thresh-hold and potential toxicity. A sample of Skylab water was profiled for volatile organics and the results are shown in Figure 7. This water does not appear to have a profile of a urine distillate as the previous systems and the compounds identified may indicate contaminants arising from the system and/or storage containers.

Figure 8A, B, and C compare raw urine, treated urine (BioPal VRO-20; H_2SO_4; Dow Corning antifoam) and product water regenerated from treated urine, respectively (Southwest Research Institute). This type of comparison is preferred for the evaluation of regeneration systems and can be used for the determination of sources of the contaminants. Based on retention times alone (since GC-MS was used only for the product water) a general comparison may be made between these chromatograms. Peaks numbered in Figure 8B not appearing in the starting urine could have come from the additives and, even after regeneration, peak number 1 is found in the product water (Figure 8C). Although the product water appears to be devoid of many urine volatiles, new compounds appeared in addition to those found in the treated urine.

4.2 Quantitation of Volatile Organics

The results of the qualitative volatile organic profile work previously described combined with the knowledge of organoleptic sensitivities indicated the need for quantitating volatile organic compounds in water to the low ppb concentration level. The success of the Tenax solid adsorbent sampling and analysis procedure in qualitative work led us to select this technique for quantitative development.

FIGURE 7

VOLATILE ORGANIC PROFILE OF SKYLAB WATER

X160

5 7 9 10

33

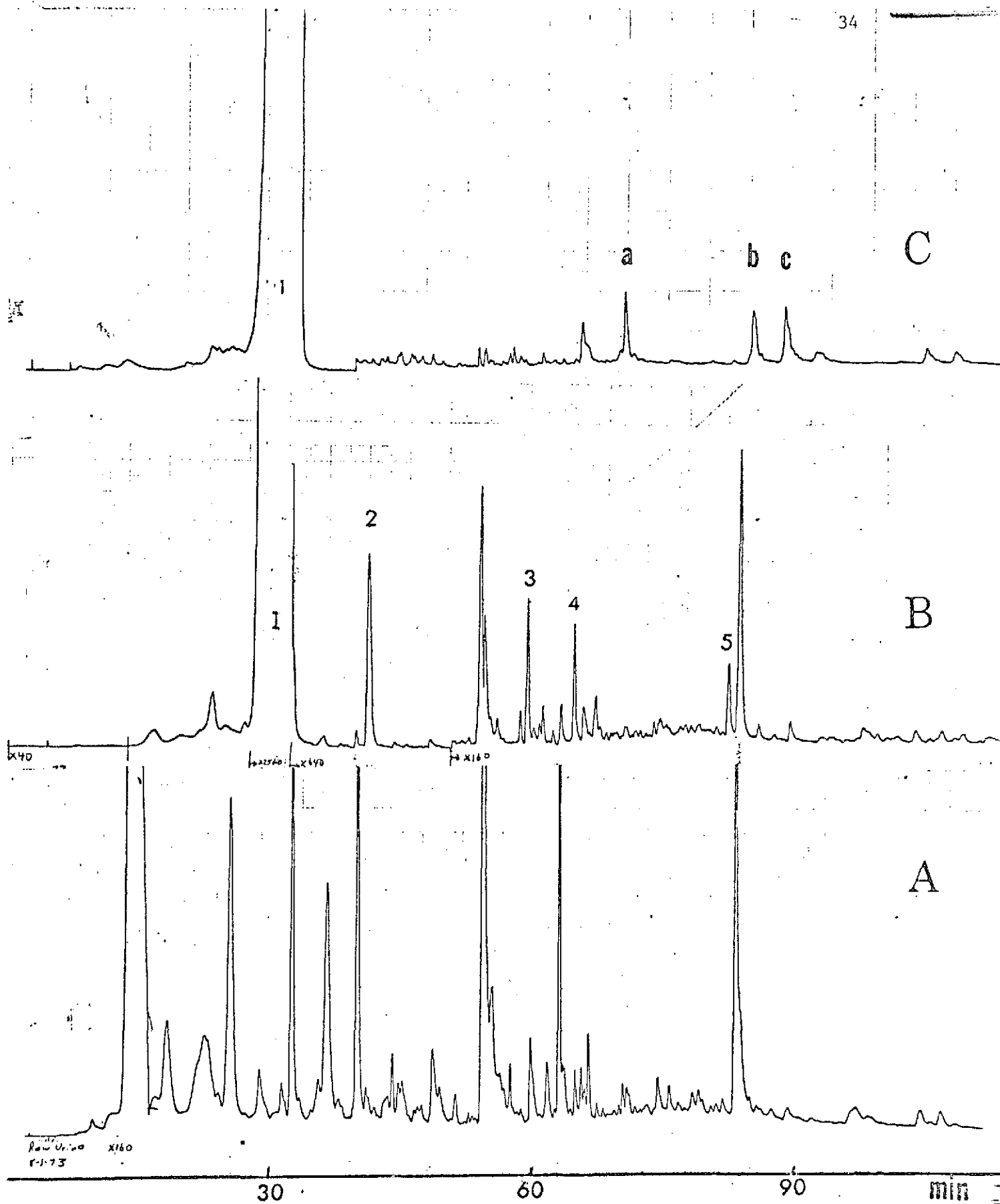FIGURE 8

COMPARISON OF VOLATILE ORGANIC PROFILES

(SOUTHWEST RESEARCH INSTITUTE)

A. Raw Urine

B. Treated Urine

C. Product Water

4.2.1 Discussion

For the Tenax procedure to be of general use it must be capable of sampling organic compounds of differing polarity, volatility, dissociation, and chemical stability. In this particular application compounds indigenous to human urine or degradation products of urine metabolites were of primary interest.

With these thoughts in mind the following four compounds were chosen for evaluation of the quantitative reproducibility and sensitivity:

2-butanol	$\overset{\overset{\text{OH}}{\mid}}{CH_3CH_2CHCH_3}$	b.p. $100^{O}C$
p-dioxane		b.p. $101^{O}C$
4-methyl-2-pentanone	$CH_3-\overset{\overset{O}{\mid\mid}}{C}-CH_2-\overset{\overset{CH_3}{\mid}}{CH}-CH_3$	b.p. $117^{O}C$
pyrrole		b.p. $131^{O}C$

These compounds show partial to very good solubility in water, varying degrees of dipole moment, and a boiling point range which makes simple distillation from a water matrix difficult. In addition, all of these compounds are known to be present in human urine, having been observed in product water from urine reclamation systems (Table 4). Vigorous conditioning of the Tenax traps (24 hours at $225^{O}C$) removed all interfering artifacts for the compounds of interest. Sampling system blanks showed

background to be less than 10×10^{-9} grams. Blanks from the deionized water used for preparing the secondary standard however showed a large number of interferants at levels greater than 1 ppm. It was necessary to boil the DI water with hydrogen peroxide in order to reduce these contaminants. This reduced interference with 2-butanol, 4-methyl-2-pentanone, and pyrrole to less than .2 ppb. However, p-dioxane interference was reduced to only 6 ppb.

Recovery tests, using the spiked standards, as described in 3.1.3 were initiated. Initial recovery for p-dioxane was less than 10% and less than 4% for 2-butanol, 4-methyl-2-pentanone, and pyrrole. Since injections of these standards directly onto a Tenax trap showed negligible loss of sample, it was felt that the compounds were not being volatilized from the aqueous phase. Tests were rerun eliminating the water bath for heating in favor of refluxing.

Figure 9 is a chromatogram of a direct injection containing 2.5×10^{-6} grams each of the four compounds. Figure 10 shows a typical sampling system blank (note the lower attenuation) and Figure 11 is a chromatogram of a 50 ppb spiked sample sampled with Tenax. Table 5 presents area response for standardization. Table 6 presents area response for the sampling system blanks. Table 7 shows area response for the recovery tests of samples spiked with 50, 25, and 5 ppb quantities. As can be seen from Table 7, precision calculated at one standard deviation ranges from approximately 10 to 20 percent and recovery from 68 to 88%. The recovery values are plotted in Figure 12 and calibration curves drawn for the four compounds. The linearity and data point spread appear good. The large data point spread of dioxane is probably due to the large and variable blank.

FIGURE 9

DIRECT INJECTION OF FOUR COMPONENT QUANTITATIVE STANDARD

pyrrole

4-methyl-2-pentanone

p-dioxane

2-butanol

2μl

X 640

FIGURE 10

QUANTITATIVE SAMPLING SYSTEM BLANK

0.48

X 40

FIGURE 11

TENAX HEADSPACE SAMPLING OF SPIKED WATER SAMPLE

X 640
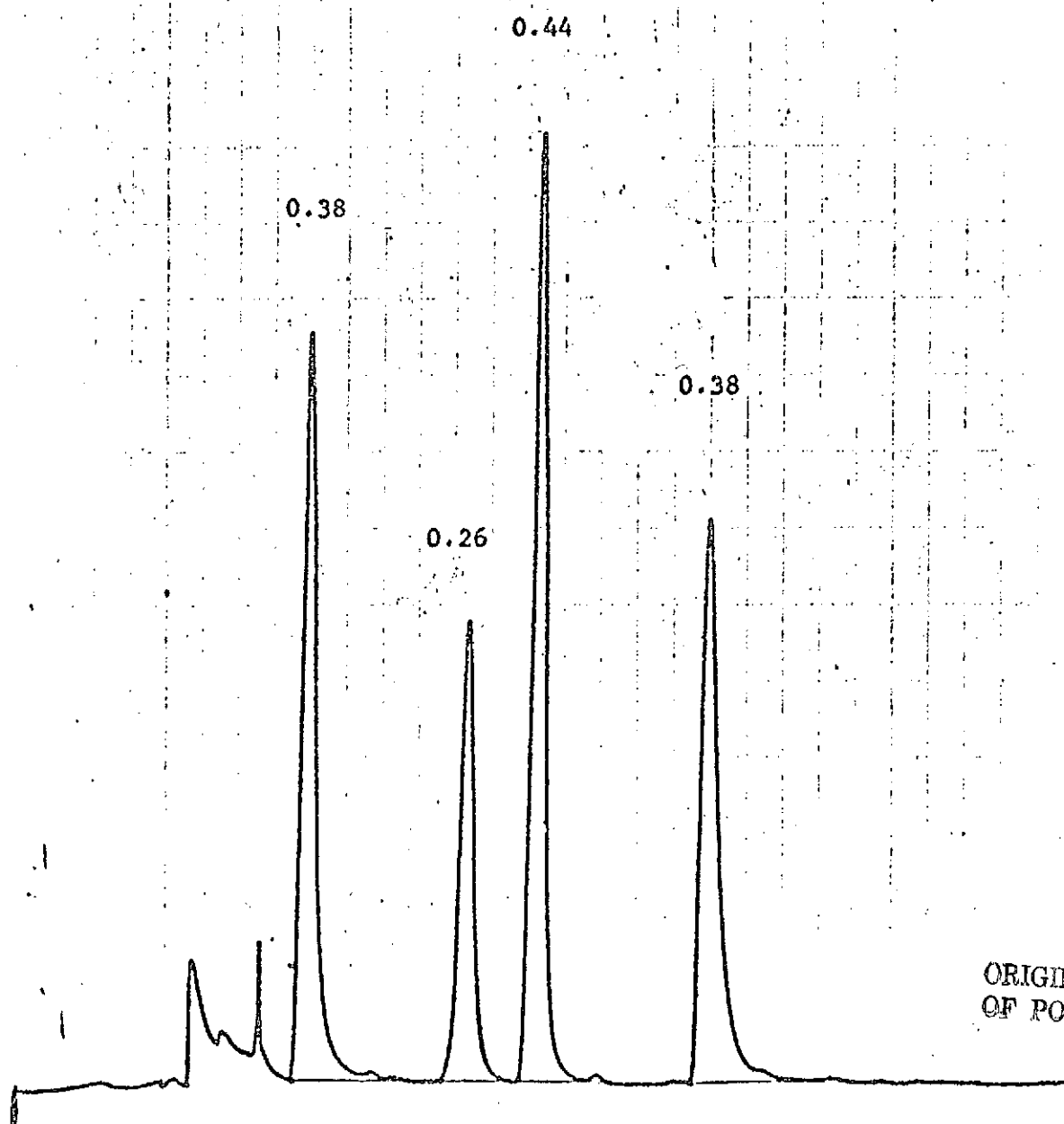
TABLE 5

AREA RESPONSE FOR 2.5×10^{-6} gm STANDARDS

Run	2-butanol	p-dioxane	4-methyl-2-pentanone	pyrrole
1	288	160	320	512
2	275	160	288	294
3	275	154	282	294
4	301	186	294	294
5	282	186	294	294
Average	282	166	301	301

TABLE 6

AREA RESPONSE FOR SAMPLING SYSTEM BLANKS

Run	2-butanol	p-dioxane	4-methyl-2-pentanone	pyrrole
1-20	–	18.8	–	–
3-15	–	12.4	–	–
1-22	–	19.2	–	–
5-13	–	24.4	–	–
Average	–	18.8	–	–
Calculated as grams		0.3×10^{-6} gms		

TABLE 7

RECOVERY OF STANDARDS FROM SPIKED SOLUTIONS

Recovery of Standards from 50 Milliliters of 50 ppb Water Solution

Run	2-butanol	p-dioxane	4-methyl-2-pentanone	pyrrole
2-16	237	160	275	262
4-13	256	147	320	275
6-14	–	102	282	198
2-18	262	147	269	250
2-20	243	166	282	243
7-10	275	96	288	256
9-2	211	128	186	198
Average	250	134	269	243
Calculated as grams	$2.2^{\pm}.2 \times 10^{-6}$	$2.0^{\pm}.4 \times 10^{-6}$	$2.2^{\pm}.4 \times 10^{-6}$	$2.0^{\pm}.2 \times 10^{-6}$
Blank correction	–	$.3 \times 10^{-6}$ gms	–	–
Recovery	88%	68%	88%	80%

TABLE 7 CONTINUED

RECOVERY OF STANDARDS FROM SPIKED SOLUTIONS

Recovery of Standards from 50 Milliliters of 25 ppb Water Solution

Run	2-butanol	p-dioxane	4-methyl-2-pentanone	pyrrole
1	108	54.4	114	73.6
2	119	59.5	111	113
3	108	58.5	123	108
Average	112	57.5	116	98.2
Blank correction	–	18.8	–	–
Recovery	97%	50%	88%	72%

Recovery of Standards from 50 Milliliters of 50 ppb Water Solution

Run	2-butanol	p-dioxane	4-methyl-2-pentanone	pyrrole
1	23.1	26.4	26.4	12.0
2	25.0	36.0	26.6	27.8
3	25.0	–	27.2	22.0
Average	24.4	31.2	26.7	20.6
Blank correction	–	18.8	–	–
Recovery	107%	80%	100%	74%

FIGURE 12

RECOVERY OF STANDARDS FROM CONCENTRATIONS ON TENAX
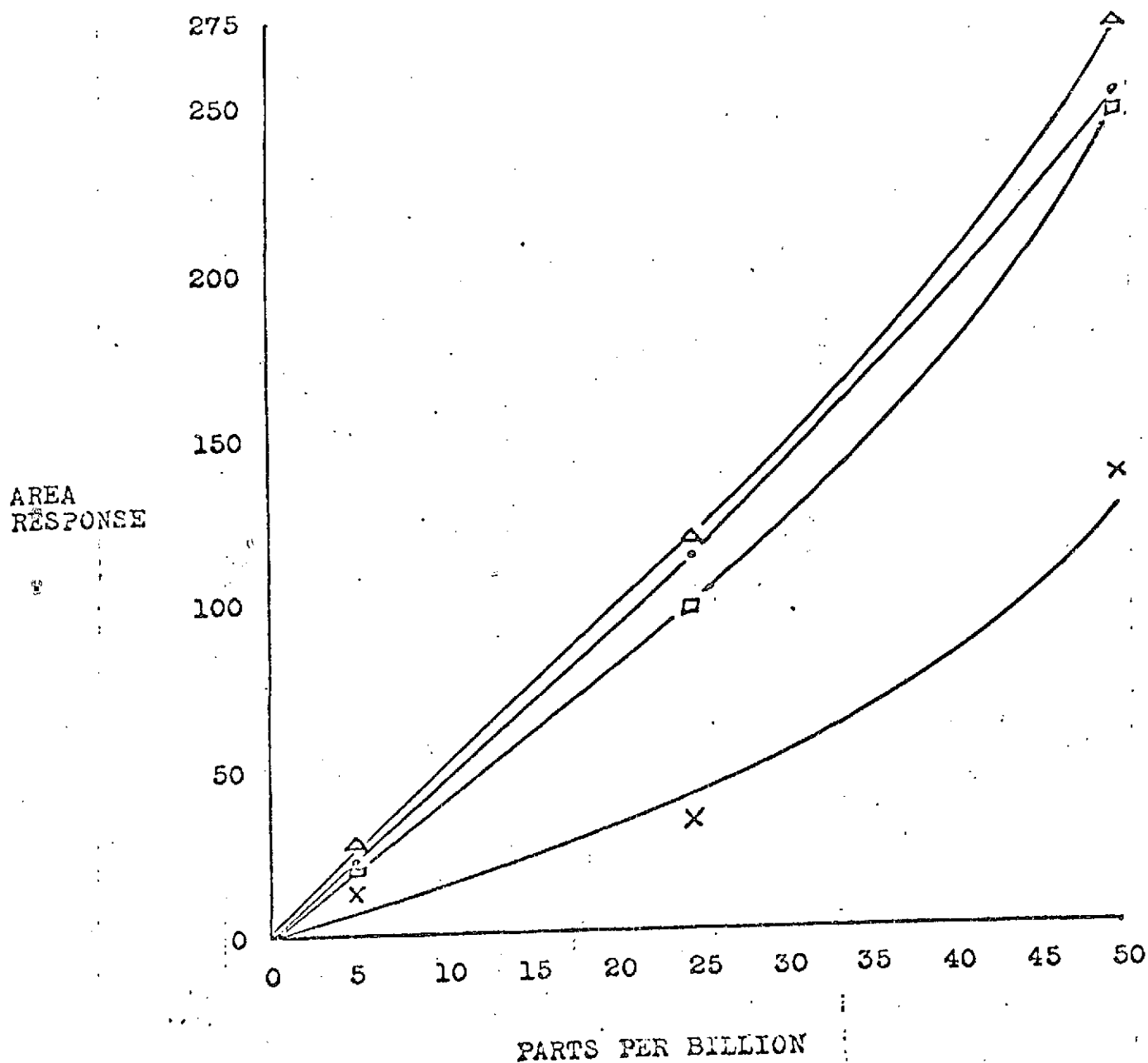
•	=	2-butanol
✕	=	p-dioxane
△	=	4-methyl-2-pentanone
□	=	pyrolle

4.3   Taste Panel Evaluations

Synthetic water samples have been made up and tasted with the
objective of establishing the minimum essential ingredients to achieve good
taste based on the enhancement factors identified in Table 2.   The samples
were prepared from ultrapure water to insure that no negative factors were
present.   Initially three samples of water were made up with the
following concentrations (mg/l) of Ca, Mg, K and Na ions:

	Ca	Mg	K	Na
Water #1	≪0.1	≪0.1	≪0.1	≪0.1
Water #2	20	10	0	2
Water #3	40	10	2	10

Total organic volatiles were determined quantitatively by the solid adsor-
bent trapping and analysis method and verified less than 0.2 ppb for
all three matrices.   Three tasters were used and samples were tasted at
room temperature and $40^\circ F$.   Two of the tasters did not know which samples
they were tasting while one did.

Table 8 presents comparisons of preference and a summation of the
times each water was selected in a certain category.   Tasters were asked
not to describe waters as tasting good or bad but to rank them in order of
preference.   Tasters I and II made a repeat on a succeeding day to see if
any changes were made in preference.   Taster I made a reversal in least
and better but both tasters selected the same water as best that they had
the day before.   There is a remarkable difference in taste preference for
waters #2 and #3 versus water #1.   The ultrapure water was never selected
as being best tasting while it was the least desirable seven times.   The
samples with added electrolytes showed no great difference in preference.

TABLE 8

PREFERENCE FOR SYNTHETIC WATERS

TASTE PREFERENCE

Room Temperature (day 1)	Least	Better	Best
Taster I	#3	#1	#2
Taster II	#1	#2	#3
Taster III	#1	#2	#3
40 F (day 1)	Least	Better	Best
Taster I	#1	#3	#2
Taster II	#1	#2	#3
Taster III	#1	#3	#2
Room Temperature (day 2)	Least	Better	Best
Taster I	#1	#3	#2
Taster II	#1	#2	#3

NUMBER OF TIMES A WATER SELECTED IN A CATEGORY

Water #	Least	Better	Best
Water #1	7	1	0
Water #2	0	4	4
Water #3	1	3	4

The above test indicated that water with some added ionic constituents is obviously preferable to "zero" pure water. A second test was conducted in an attempt to better define the concentration range of the various anions and cations which produce the best tasting water. Again all samples were made up from water containing less than 0.2 ppb volatile organics, less than 1 ppm total organic carbon, and less than 0.1 ppm of any of the anions and cations to be added; the values for the latter two being the limits of detection. It is necessary to start with water that is both organically and inorganically pure in order to be certain that any taste qualities are truly attributableto the added components. It should be noted also that dissolved gas content was not controlled in these tests but should be very low (less than 0.1 ppm), since the water was purified by distillation.

The water samples for the second taste test were made up to the anion and cation contents given in Table 9. Six different samples were tested one of which (#5) was tap water. The taste panel was made up of six members who were instructed to taste each water individually and state whether it was bad, average, or good tasting. At the conclusion each was asked to select the best tasting water. No attempt was made to remove bias, nor was any attempt made to influence a preference. All samples were tested at room temperature. Evaluations and comments of the tasters are presented in Table 10. As anticipated the waters with high (sample #6) and no (sample #4) electrolyte content were rated objectionable or not as pleasing as others. Since the tap water sample was not highly rated it was not chemically analyzed. It should be noted that the taste panel could not select an

TABLE 9

CHEMICAL COMPOSITION OF SYNTHETIC SAMPLES FOR TASTE EVALUATION

	#1	#2	#3	#4	#5	#6
Ca^{++}	20	25	15	0.1	T	40
Mg^{++}	20	25	7.5	0.1	A	40
K^+	10	5	1	0.1	P	20
Na^+	10	5	5	0.1	(well)	20
$SO_4^=$	40	50	15	0.1	W	80
Cl^-	35	43	26	0.1	A	70
NO_3^-	69	74	1.6	0.1	T	122
HCO_3^-	28	14	14	0.1	E	28
					R	

TABLE 10

TASTE PANEL EVALUATION OF SYNTHETIC WATER SAMPLES

Sample Number	Taster Comments		
1	(1) Hard, like apartment water	(2) Good tasting	(3) Good tasting
	(4) Good tasting	(5) Good tasting	(6) Good
2	(1) Less hard than #1, all right	(2) Not as good as #1, but still good	(3) Not as good as #1, but still good
	(4) Good tasting	(5) Did not like	(6) Slightly saline
3	(1) Similar to #1 and #2	(2) Good tasting	(3) Good tasting
	(4) Good tasting	(5) Good tasting	(6) Pleasing
4	(1) Do not like at all	(2) Bad tasting	(3) Bad tasting
	(4) Bad tasting	(5) Better than #2 or #3	(6) Bad tasting
5	(1) Best one	(2) Same as #2	(3) Mineral or iron taste
	(4) Mineral or iron taste	(5) Left film on tongue	(6) Medicinal flavor
6	(1) Similar to #4, bad	(2) Not as good as #2, but drinkable	(3) Good, but not as good as #1
	(4) Flat tasting	(5) OK	(6) Left an after-taste

(Taster number)

obvious best sample and that samples #1 and #3 were generally equally good. Based on these results it is felt that the following salt concentrations should be added to product water from water reclamation systems for further taste evaluations; with the provision that a portion of either the K^+ or Na^+ may later be added as a fluoride for physiological reasons.

Ca^{++}	20 ppm (as $CaCl_2$)
Mg^{++}	10 ppm (as $MgSO_4$)
K^+	2 ppm (as KCl)
Na^+	10 ppm (as $NaCl$)

5.0 CONCLUSIONS AND RECOMMENDATIONS

   5.1 Spacecraft Water Quality-Palatability Specifications

      The principal areas which must be addressed in any set of space-
craft water quality-palatability specifications are summarized below:

   (1) Toxicity

   (2) Physiological requirements

   (3) Psychological aspects

   (4) Appearance

   (5) Palatability

Toxic chemical constituents to be included must be related to the par-
ticular spacecraft and water system as well as the duration of the mission.
If the water system is regenerative, the raw material source (e.g., urine
and/or foecal matter) must be considered since compounds not efficiently
removed by the regeneration process could build up to potentially toxic
levels. Exogenous sources of potentially toxic compounds (e.g., spacecraft
outgassing) could also be concentrated in the drinking water if they
are not efficiently removed.

   The question of physiological requirements was discussed with
Dr. Malcolm Smith, Branch Chief, Food and Nutrition Branch, NASA-JSC. It
was agreed that all mineral balance and trace element deficiencies would
be compensated for in the food supplies. Any adjustments required to
include the contribution from the water supply will be made at a later date
when the chemical definition of the water is completed.

   Psychological aspects involving consumption of regenerated or reclaimed
water will require the user to be educated in the design and operation of the
system.

Values have been established for the factors which determine appearance and palatability. These values are given in Table 11 and can serve as a basis for any further evaluation of palatability factors. The values given for color and total solids are perhaps superfluous as it is difficult to imagine these values being above specified limits if all other specifications are met. The values for inorganic chemical constituents reflect the limited taste panel studies conducted in this study and are valid only if the organic constituents are below the specified levels. No value can be set for single volatile organic components until more quantitative information becomes available on the effect of various organic compounds. This specification need concern only those compounds found to be associated with a particular water system and should also consider any toxicity problems which such compounds may present. This specification also lists several chemical constituents and other properties which are thought to be important for water palatability but have not yet been evaluated. It is not known which of these factors are actually essential for good tasting water and whether there are synergistic or antagonistic effects for various combinations of these factors. Such knowledge is essential in order to establish final palatability criteria. A detailed examination of these palatability factors should be undertaken in future work.

5.2 Evaluation of Spacecraft Water Reclamation Systems

The results of inorganic, nonvolatile organic, and volatile organic profile analysis of reclaimed water samples completed during this study indicate that nonvolatile and volatile organic compounds are not

TABLE 1.1

SPACECRAFT WATER QUALITY-PALATABILITY SPECIFICATIONS

*APPEARANCE

Color - ⩽5 on cobalt scale

Total solids - less than 50 ppm

*PALATABILITY

Dissolved gases

CO_2: 1-5 ppm

O_2: 1-5 ppm

Chemical Constituents - Inorganic

Ca^{++}:	$20^{+}_{-}5$ ppm	Cl^-:	$30^{\pm}10$ ppm
Mg^{++}, Na^+:	$10^{+}_{-}2$ ppm	$SO_4^=$, $NO_3^=$:	$40^{\pm}10$ ppm
K^+:	$2^{\pm}1$ ppm	$HCO_3^=$, $CO_3^=$:	$10^{\pm}5$ ppm
Cl^-:	$30^{\pm}10$ ppm		
$SO_4^=$, $NO_3^=$:	$40^{\pm}10$ ppm		

Chemical Constituents - Organic

Nonvolatile

Total Organic Carbon (TOC):   ⩽1 ppm

Dissolved Organic Carbon (DOC):   ⩽1 ppm

Particulate Organic Carbon (POC): ⩽1 ppm

Volatile

Total Headspace Extractable: 1 ppm

Single Headspace Extractable: To be determined

removed to the low concentration levels consistent with palatability. These results have been somewhat confused by the lack of contamination control in the sampling and sampling handling procedures used to examine these pilot reclamation systems; however the need for an independent evaluation of potential reclamation systems has been clearly established.

The preliminary results obtained in evaluating the ability to quantitate volatile organics with the Tenax solid adsorbent trapping and analysis procedure are very encouraging. It is apparent that this technique has a very high potential in the future evaluation of spacecraft water reclamation system, and should be exploited to the fullest possible extent.

An effort should be made to evaluate the prototype water reclamation systems selected for future use in spacecraft by working with the organization operating the prototype system to establish proper sampling and sample handling procedures; and to perform analysis of such samples for inorganic, nonvolatile organics, and volatile organics which effect palatability as defined in the palatability specifications developed during this program (see Table 11). The attainment of qualitative and quantitative data on specific organic compounds may provide extremely valuable information related to palatability and toxicity and will provide a basis for determining if any in-flight monitoring is necessary. It is clear that a concern for accepting palatability cannot be separated from the evaluation of regeneration systems in terms of the presence of potentially toxic compounds which may constantly be recycled (and therefore concentrated) in a spacecraft environment. Once these potential toxic and unpalatable organics are known to be removed, suitable inorganics may then be added for good taste.

The following bibliography lists those books and articles found in our literature search which have some bearing on the problem of enhancement of the taste of potable water supplies.

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7.0 SUMMARY

The principal factors affecting water quality and palatability are
the presence of dissolved gases, the concentration of various inorganic
cations and anions and the organic carbon content. Organic carbon can be
differentiated as nonvolatile and volatile organic matter. The latter is
of greater significance in palatability considerations since both taste
and odor contribute to palatability. Volatile organic compounds present
in parts per billion (ppb) concentrations in water can have negative
effects on palatability and may also affect water quality from the stand-
point of toxicity. A new solid adsorbent trapping and analysis system has
been applied to the qualitative analysis of volatile organic compounds
in product water of several spacecraft water reclamation systems. Con-
ventional atomic adsorption analyses for the palatability related inorganic
constituents were also carried out. The results indicated that organic
constituents were not removed efficiently and may be responsible for the
poor taste of these waters. The solid adsorbent system was further de-
veloped for quantitation of organic volatiles and shown capable of
quantitation at the 5-50 ppb level. This technique was used to verify that the
volatile organic content of synthesized water samples was sufficiently
low to not contribute negative palatability. Inorganic constituents were
added to the ultrapure water and the resultant samples evaluated by a
taste panel. The results of these taste tests and the other information
above have been incorporated into a specification for spacecraft water
quality-palatability. The application of the solid adsorbent trapping
and analysis system to the evaluation of the water reclamation system

chosen for future spaceflights can greatly enhance our ability to further define spacecraft water criteria.

8.0 APPENDIX

8.1   List of Figures

8.2   List of Tables